TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 43

NOTE ON THE RESISTANCE OF POLISHED CYLINDERS (AND CYLINDRICAL WIRES) WITH GENERATRICES PERPENDICULAR TO THE AIRSTREAM.

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Translated from the French,
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Paris Office, N.A.C.A.

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There are a great number of experimental papers relating to this question. It may be useful to recall them.

1st. An English document (N.P.L. Report No.102, March, 1914) summarizes all the experiments made up to that date at the N.P.L. on cylinders and smooth piano-wires. These experiments were made on wires of various diameters, from 0.05 mm. to 31.75 mm. The velocity of the airstream varied from 3 m:sec. to 15.25 m:sec. The ensemble of the results found were represented graphically as follows:

The quotient $\frac{F}{\rho V^2 d^2}$ was laid off as an ordinate, and Log. $\frac{Vd}{\nu}$ as an abscissa. F is the resistance of a length of cylinder equal to the diameter; ρ is the specific mass of the air (0.125 at 15° and 760 mm.); ν is the kinetic coefficient of viscosity. (For air at 15° and 760 mm.: $\nu = 1.475 \times 10^{-3}$ in C.G.S.).

* Taken from "L'Aeronautique," No. 11, April, 1920.

We may remark that $F = K\,d^2V^2$ calling K the coefficient usually employed in France to express the unit resistance referred to the diametrical surface.

We have thus

$$K = \left(\frac{F}{\rho V^2 d^2}\right)\rho = \left(\frac{F}{\rho V^2 d^2}\right) \quad 0.125.$$

We have reproduced the curve

$$\frac{F}{V^2d^2} \qquad \frac{Vd}{v}$$

in more usual notations.

The coefficient K is laid off in ordinates (Fig. 1) and Log Vd or Vd in abscissas (on a logarithmic scale).

The curve given by the English Report constitutes a scientific document of great importance, since it confirms the law of dynamic similitude for values of $\frac{Vd}{v}$ within wide limits.

2nd. An English report (N.P.L. Report No.103, October 1914) gives the pressures on a cylinder of 50.8 mm. diameter for a length of 0.457 (9 diameters) and for an infinite length. The experiments were made at a speed of 9.15 m:sec.

The results obtained are shown on Fig. 2.

The maximum pressure forward is such that $\frac{H\infty}{V^2} = 0.0625$.

The angle of passage from the zone of pressure to the zone of depression is about 71° for the cylinder of infinite length and about 77° for the cylinder whose length is equal to 9 diameters.

Also, the depressions are greater with the cylinder of infinite length than with the cylinder of finite length.

Calculating the coefficient K as stated. we find the following results:

Cylinder D = 50.8 mm.; L = 457 mm.; K = 0.043 for Vd = 0.464

Cylinder D = 50.3 mm.; L = ∞ ; K = 0.067 for Vd = 0.464

It has moreover been verified, by direct measurement with a balance, that the total resistance on a portion of the tube of infinite length also gives K = 0.067.

This proves that the resistance due to friction on the surface of the cylinder is negligible or is of the order of magnitude of errors made in experiments (0.5%).

If we also measure the total force on the cylinder of limited length, we find K = 0.05.

This proves that the distribution of pressure is not the same in all the diametral sections of the limited cylinder and that the forces of friction on the terminal surfaces are not negligible.

Point K = 0.067 for Vd = 0.464 is placed below the curve previously given.

3rd. An English report (N.P.L. Report No.191, March, 1916) describes experiments similar to those given above, made on a cylinder of 152 mm. in diameter (length not given in the Report).

Moreover, the English author considers that the diameter of the cylinder was too large to allow of its being put in a tunnel measuring 1.21 m. sidewise. He considers that the results found have merely a qualitative value.

These results are given in Fig. 3.

For speeds of 6.096 and 9.145 m:sec., the curves $\frac{H\infty}{V^2}$ coincide.

It is not the same for the speeds of 12.192 and 16.75 m:sec.

The author considers that he has found a change of unit resistance similar to that noted for spheres at certain values of Vd.

Calculating the coefficient K, we find:

For V = 6 to 9.14 m:sec.; K = 0.0573 that is for Vd = 0.9 to 1.37
For V = 12.192 m:sec.; K = 0.0512 " " " " = 1.84
For V = 16.75 m:sec. ; K = 0.033 " " " " = -2.54

4th. We may further mention the experiments of Morris and Thurston (East London College Laboratory) on cylindrical bars of various diameters. (The Aeronautical Journal, No. 58, April, 1911).

The results found are given in the following Table:

d	V	Vd	K	d	V	Vd	K
30.8	8.95	0.455	0.05525	21.7	8.95	0.195	0.07080
44.5	"	0.400	0.05750	21.6	"	0.193	0.0690
38.1	"	0.340	0.06270	13.5	"	0.121	0.0668
31.8	"	0.285	0.06715	10.4	"	0.093	0.0658
24.8	"	0.222	0.07000	7.8	"	0.070	0.0603

These points are also shown on Graph Fig. 1 and define a curve marked (MT) which at first accords with the curve A for values of Vd less than 0.2. For Vd > 0.2, the results obtained by these experimenters show a fairly rapid decrease of the coefficient K with Vd.

5th. (a) STANTON'S EXPERIMENTS (East London College Laboratory). On a wire 1.66 mm. in diameter and 410 mm. long, the following results were found:

K = 0.062 for V = 4.6 m:sec., that is Vd = 0.0074

K = 0.0-1 for V = 5.3 m:sec., that is Vd = 0.0085.

These points are marked (S 1.6) on Graph Fig. 1. They accord fairly well with Eiffel's results on a wire of 1 mm., but they do not accord with the curve A which, for Vd comprised between 0.01 and 0.005, rises again to K = 0.08.

(b) Dr. PRANDTL'S EXPERIMENTS (Göttingen Laboratory). The results found on a polished wire 4.3 mm. in diameter are given in the following Table:

d	V	Vd	K
4.3	4.63	0.0186	0.0601
4.3	8.00	0.0322	0.0593
4.3	9.65	0.0390	0.0605

These results agree fairly well with those of the Eiffel Laboratory and do not notably deviate from Curve A.

In the same Göttingen Laboratory, Föppl, having studied the resistance of the air on wires from 0.05 mm. to 30 mm. in diameter for speeds going from 4.6 to 9.6 m. per second, found that, practically, the variation of K with Vd may be represented by the relation

$$K = 0.082 - 1.74\ Vd \text{ for } 0.001 < Vd = 0.015$$

and

$$K = 0.066 \text{ for } Vd > 0.015$$

Föppl's law is also shown on Graph Fig. 1 in (Fo).

Lastly, in the "Technische Berichte" (Table 111, Dec. 20, 1917) we find the results obtained during the War at Göttingen on a round strut 100 mm. in diameter, tested at speeds up to 40 m:sec.

These results are marked (Mu) on Graph Fig. 1.

II - M. EIFFEL'S EXPERIMENTS.

In his Volume "The Resistance of the Air and Aviation" (experiments made in the Champ de Mars Laboratory in 1911), M. Eiffel gives the following results:

Cylinder	D = 150 mm.;	L = 600 mm.	(4 diameters),	K = 0.040
Cylinder	D = 30 mm.;	L = 1000 mm.	(33 "),	K = 0.060
Wire	D = 2.75 mm.;	L = 500 mm.		K = 0.063

For speeds going from 5 m:sec. to 20 m:sec.

In the volume "New Researches on the Resistance of the Air and Aviation" (experiments at the Auteuil Laboratory, 1914), M. Eiffel gives the following results.

				For V = 24 m
Wires,	1 mm.	L = 600 mm.	(K varies with V)	K mean = 0.0605
"	1.5 mm.	L = 600 mm.	"	K mean = 0.0610
"	2 mm.	L = 600 mm.	"	K mean = 0.0585
"	2.5 mm.	L = 600 mm.	"	K mean = 0.0585

Bringing these various coefficients to the speed of

24 m:sec., we find the corresponding values of Vi. On Fig. 1 we have laid off the points thus obtained, and also those relating to the wire of 1 mm. diameter for various speeds.

The former practically accord with the English curve. Not so the points relating to the wire of 1 mm. diameter. These give a curve quite different from the English curve, especially at low values of Vd (Curve E_1).

Finally, we have still the tests on cylinders of VERY LIMITED length. Of these we retain only the results relating to a cylinder D = 150 mm., L = 225 mm. (1.5 d).

These results are also laid off on Graph Fig. 1.

In experiments made in 1918, M. Eiffel found very interesting results which clearly show that, on cylinders of large fineness ratio the coefficient K decreases rapidly for values higher than Vd = 1.

His experiments were made on the following cylinders for speeds comprised between 14 m:sec. and 30 m:sec.

D = 0.196	L = 1.50	$\frac{L}{D} = 7.61$
D = 0.146	L = 1.50	$\frac{L}{D} = 10.27$
D = 0.105	L = 0.735	$\frac{L}{D} = 7.00$
D - 0.0975	L = 1.50	$\frac{L}{D} = 15.4$
D - 0.0485	L = 1.50	L/D = 31.

The results obtained are shown on Graph Fig. 4 and the mean curve is plotted on Fig. 1.

We observe:

1st. That the coefficient K deduced from our measurements of pressure on the cylinder $\frac{14}{250}$, that is $\frac{L}{D} = 18$ (point marked ⊙ , Saint-Cyr, 14-250) is in perfect accord with the latest results of M. Eiffel.

2nd. That the values of the coefficient K deduced from the English measurements on a cylinder 152 mm. in diameter are also in agreement with M. Eiffel's results. The opinion of the English author as to the existence of a critical zone beyond Vd = 1 is thus confirmed.

3rd. Beyond the critical zone (say for Vd < 3.5), the fineness ratio $\frac{L}{D}$ seems no longer to have an appreciable influence on the value of the coefficient K, since we have practically the same value K = 0.02 for fineness ratios going from 1.5 to 10.

4th. The Göttingen experiments have also proved the existence of a critical zone but the curve is plotted parallel to Eiffel's curve at a distance (Log Vd = 0.2).

It remains to find the cause of this divergence by an analysis of the experimental conditions. It may well be due to the degree of turbulence of the artificial airstreams utilized for these tests.

CONCLUSIONS.

In bringing together these documents concerning experiments made on cylinders, our only aim has been to show the lack of consistency between the various results published up to date. It is, moreover, necessary to make a more thorough study of the question by examining in detail the experimental conditions relating to each result and eliminating those experiments which are not strictly comparable (for instance, experiments on cylinders of limited length).

It is to this idea of the coordination of the various experimental results that the aerodynamical laboratories should turn their attention. The Laws of Aerodynamics can only be established on a scientific basis on condition of having one sole experimental law governing simple cases such as those of cylinders.

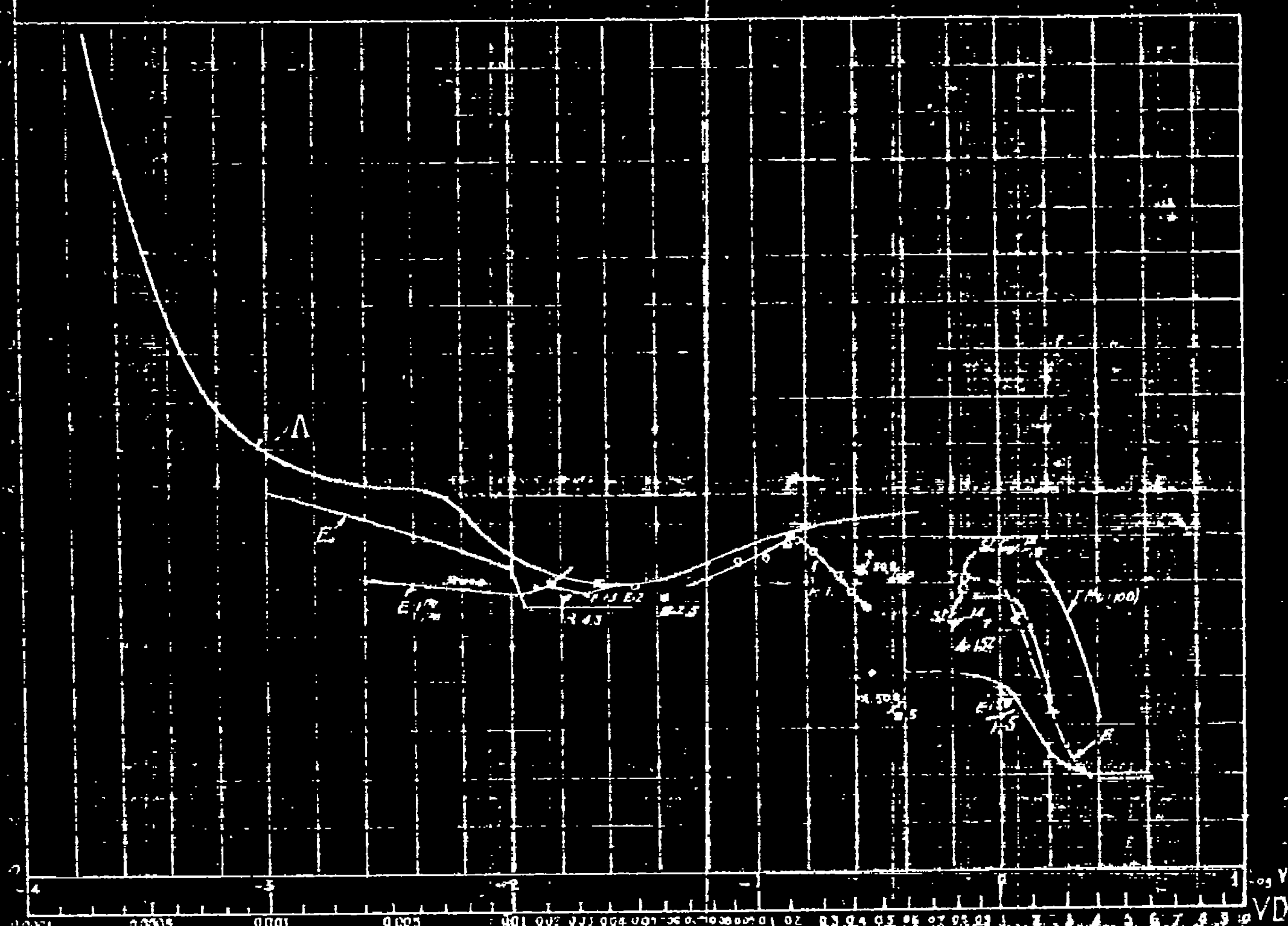

FIG. 1

General Graph of the results of various experiments on Cylinders (and cylindrical wires) perpendicular to an Airstream.

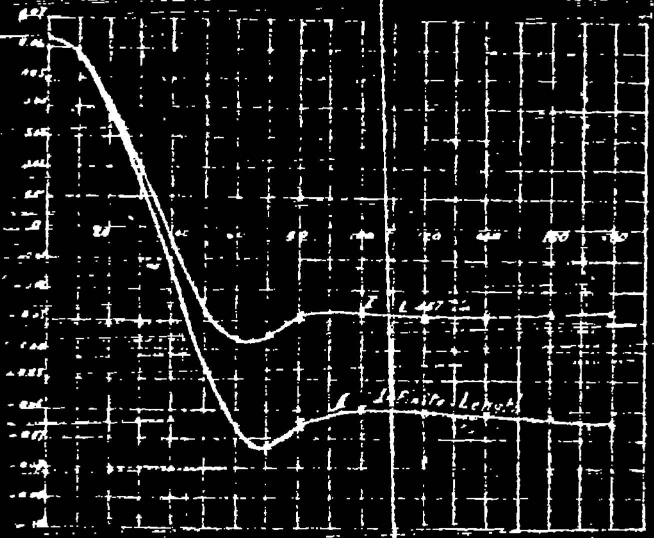

Fig.2.- Experiments of the N.P.L. Pressure $\frac{H}{V^2}$ on a cylinder.

D = 50.8; L = 457, Curve I.   D = 50.8; L = ∞, Curve II.

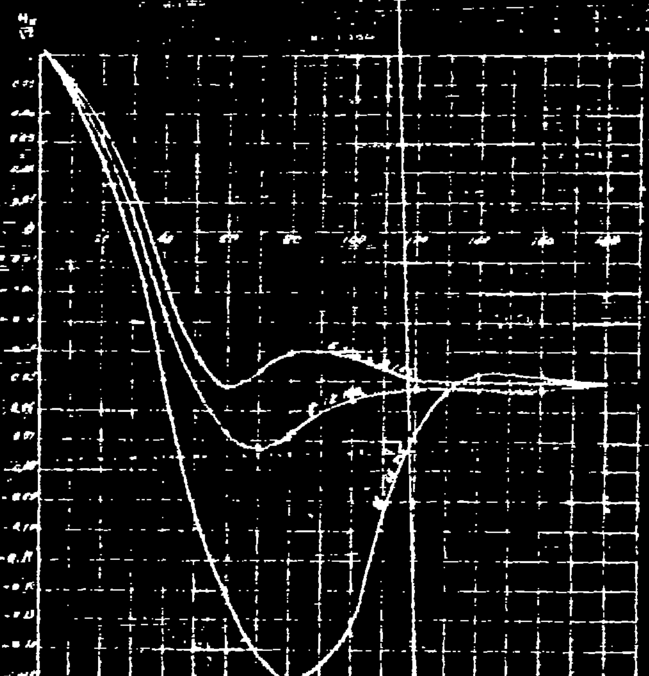

Fig.3.- Experiments of the N.P.L. Pressures $\frac{H\infty}{V^2}$ on a cylinder.

D = 152 mm; L = [illegible] mm

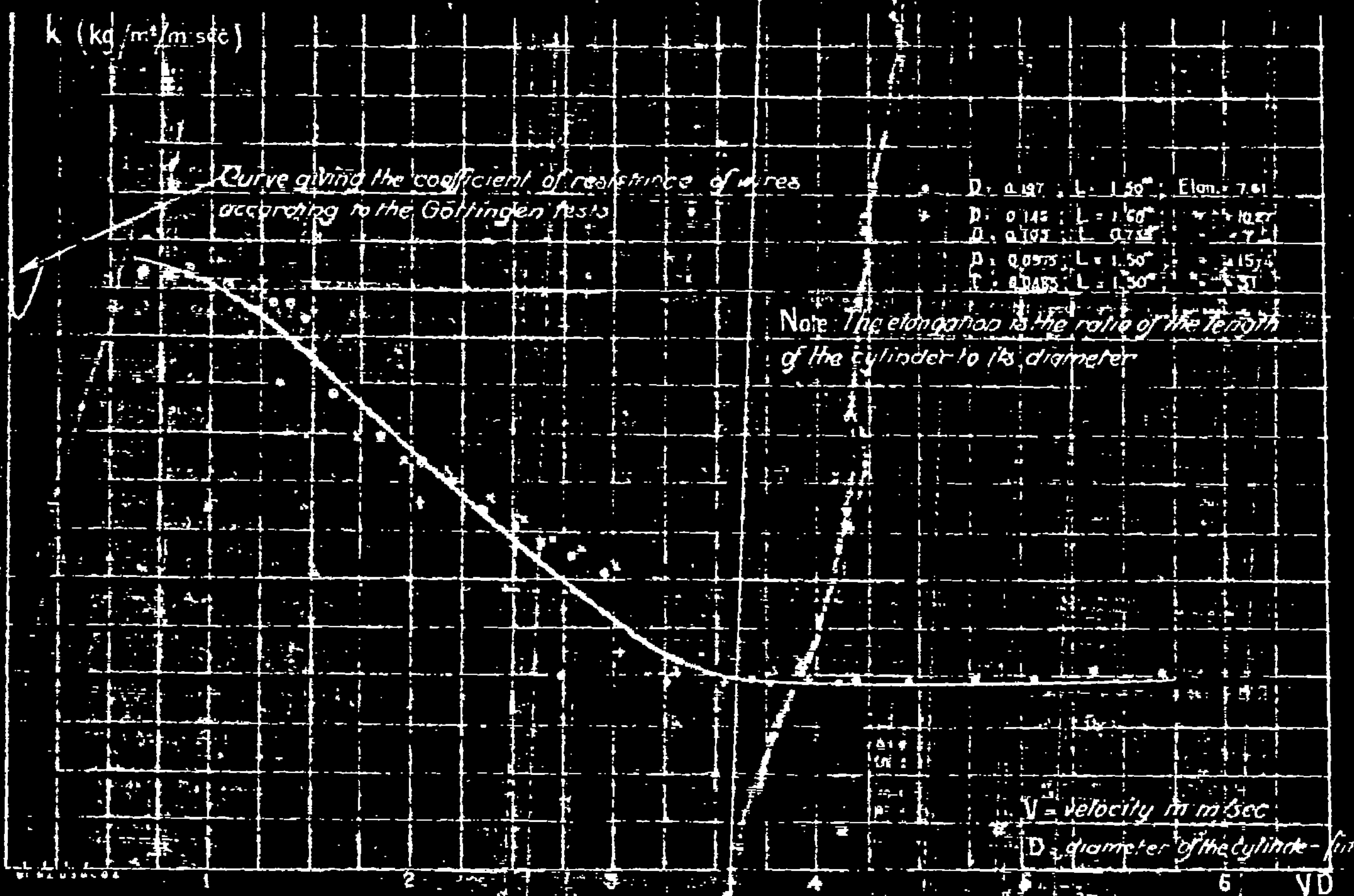

Fig.4. - Tests on Cylindrical Bodies at the Eiffel Aerodynamical Laboratory.